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COMET CUNNINGHAM, 1940c

By RUTH J. NORTHCOTT

PEOPLE are again comet-conscious because of the interest created by the press about Comet Cunningham. This comet promised to be the most interesting one since Halley's Comet in 1910, for it was predicted to attain naked-eye visibility in December, but it failed to become a really spectacular object.

It is very difficult to predict with any exactness the changes in brightness to be expected in a comet. The brightness depends both on the distance of the comet from the sun and on its distance from the earth. The general formula gives the brightness of the comet proportional to $1/\rho^2 r^n$, where ρ is the comet's distance from the earth, r is its distance from the sun, and the power n is to be determined from observation. For many comets n is close to 4. However, the value of n is sometimes as great as 6. Small fluctuations in the brightness of the nuclei of comets have been found to follow the variations in sun-spot activity. The brightness of comets has also been found to depend upon the angle of inclination of the orbit to the ecliptic, for comets that are close to the plane of the ecliptic may come into the neighbourhood of a large planet whose disturbing action may bring about the disintegration of the comet and the decrease of its brightness.

Actual estimates of the brightness of a comet are subject to systematic errors. The most important of these is due to the use of different instruments. In general the comet is estimated brighter with low-power instruments, and a difference of very nearly two magnitudes is found between estimates made with the naked eye and with a telescope of aperture greater than three

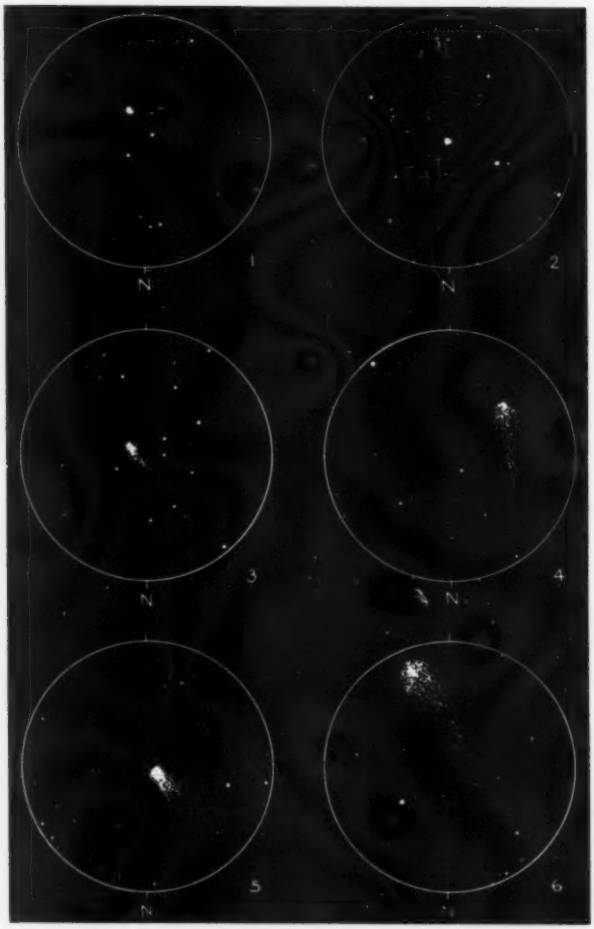

Fig. 1.—Comet Cunningham, 1940-41, sketched by DeLisle Garneau. With 4-inch refractor. Nos. 1-4, ×20; 5, 6, ×50. (See Table.)

1. Nov. 3, 9.25 p.m., Mag'de 9.
2. Nov. 25, 7.10 p.m.
3. Dec. 23, 6.20 p.m., Mag'de 4.4.
4. Jan. 1, 5.47 p.m., Mag'de 3.6.
5. Dec. 1, 8.20 p.m., Mag'de 7.2.
6. Jan. 1, 6.05 p.m., Mag'de 3.6.

inches. The phase of the moon also affects the estimates, for a bright moon reduces the apparent brightness of a comet. The degree of darkness of the sky and the presence of light clouds also affects the results.

Predictions of the changes in brightness in Comet Cunningham were published according to both the 4th and 6th power laws. It is interesting to see how the observed magnitudes compare with the predicted values.

A series of observations of Comet Cunningham has been made by Mr. DeLisle Garneau of Montreal. Figure 1 shows six of his drawings made at the eyepiece of his 4-inch telescope. Numbers 1 to 4 are with a magnification of 20 and show the development of the comet from 1940 November 3 to 1941 January 1. Numbers 5 and 6 show the detail visible with a power of 50.

Observations of Comet Cunningham by DeLisle Garneau

Date E.S.T.			R.A. 1940	Dec.	Mag.
			h m	° ′	
1940	Nov.	3.90*	19 16.8	+40 02	9
		4.82	16.6	39 38	—
		12.80*	14.6	36 38	—
		13.79	14.5	36 17	8
		20.83†	14.9	33 35	—
		25.80	16.4	31 42	—
		28.91†	17.9	30 35	7.8
	Dec.	1.84	19.0	29 22	7.2
		3.81*	20.1	28 28	7.0
		5.75	21.2	27 41	—
		9.83	23.3	25 51	7.3
		10.80	24.0	25 23	6.2
		13.80	25.8	23 58	6.0
		17.79†	28.7	21 37	5.7
		23.76*	32.3	16 50	4.4
1941	Jan.	1.75†	35.4	05 59	3.6

*Mean of two observations. †Mean of three observations.

A summary of his observations is given in the accompanying table. The comet was found to follow closely the predicted path among the stars. The magnitude estimates were made by comparison with stars in the field. Of particular interest is figure 2 showing the observed magnitudes and the predicted changes accord-

ing to the two laws. The upper curve shows the predicted magnitude changes according to the 6th power and the lower curve the changes according to the 4th power law. The observations of Mr. Garneau are indicated by open circles. Along with these are added some estimates made by Mr. Bert Topham and Dr. P. M. Millman. These are indicated by solid triangles and crosses. It would appear that according to these observations the comet

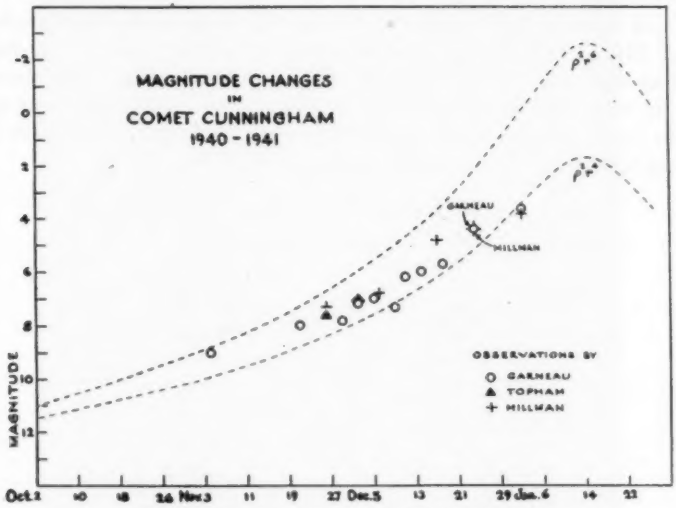

Fig. 2.—Predicted and Observed Magnitudes.
Upper curve, 6th power law; lower, 4th power. Actual observations between.

followed some law between the 4th and 6th power laws in the early stages, but was falling short of even the 4th power law as the comet approached the sun.

Although Comet Cunningham was far from being a conspicuous comet, and therefore was disappointing to the public, astronomers found it of definite scientific value since they were able to obtain a long sequence of observations of its appearance and the character of its light. These observations may lead to a clue to the origin of the solar system.

David Dunlap Observatory,
January 27, 1941.

THE 1939-40 APPARITION OF JUPITER

By Walter H. Haas and Hugh M. Johnson

Introduction

THE 1939-40 apparition of Jupiter was well presented for study from the northern hemisphere, more so than in several preceding apparitions because of the more northern declination of 0° at opposition. This paper will give the results of investigations by a small group of observers in the United States during this apparition. We shall use Universal Time (U.T.) as the basis for dates. The 1939 conjunction with the sun occurred on March 6, opposition came on September 27, and the planet was again in conjunction with the sun on April 11, 1940. At opposition the equatorial diameter was 49″.83—larger than at the preceding or following oppositions.

There have been used in this paper observations by the following amateurs:

1. W. H. Haas used the 9-inch refractor of Case School in East Cleveland, Ohio; 5-inch, 6-inch, and 8-inch reflectors in Des Moines, Iowa; two 6-inch reflectors at New Waterford, Ohio; a 10-inch refractor of Mount Union College in Alliance, Ohio; and the 12-inch refractor of Ohio State University, Columbus, Ohio. He observed from May 1 to January 10, but did almost all his best work between June 29 and September 26.

2. H. M. Johnson at Des Moines, Iowa, used after June 28 an 8-inch reflector, with which the most and best work was done, and a 5-inch reflector previous to that date. He observed from April 26 to February 25.

3. J. R. Smith at Smyer, Texas, used an 8-inch reflector in October.

4. L. J. Wilson at Nashville, Tennessee, used a 12-inch reflector visually and photographically principally from August 12 to December 18.

We have also received the beginning observations of Mr. Charles Cyrus of Lynchburg, Virginia.

Jupiter is a very fascinating object, yet there are few observers who actively work on this planet. Therefore, both for expediency in comprehending the following discussions and in the thought that there exists a definite lack of knowledge of the means for studying Jovian phenomena, we give here an outline of the planet's features and methods of studying them.

Figure 1 is a diagram showing the (1939-40) aspect of the *belts* (dark) and *zones* (light) with the nomenclature adopted by the Jupiter Section of the B.A.A. and with abbreviations which will be used hereafter. The diagram shows the planet as it is normally

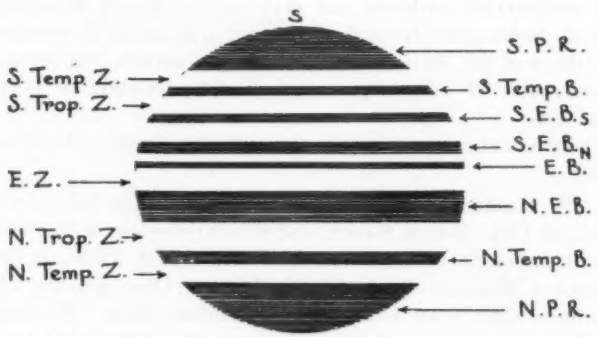

Fig. 1.—Diagram of the belt and zone system of Jupiter, 1939-40 apparition. Abbreviations: N, north; S, south; B, belt; Z, zone; E, equatorial; P, polar; R, region; Trop., tropical; Temp., temperate.

seen in the telescope from the northern hemisphere, with south at the top; the resulting direction of rotation is from right to left. Because the equatorial regions of Jupiter have a shorter period of rotation than regions to the north and south, it has been found necessary to use two systems of longitude for the planet. System I customarily is used for the equatorial regions, embracing the area between the middle of the N.E.B. and the middle of the S.E.B. between the latter's two components. System II includes the remainder of the planet. The adopted rotation periods of the two systems and hourly motions are:

	Period	Hourly Motion
I	9h 50m 30.003s	36°.580
II	9 55 40.632	36 .262

From data in published ephemerides* which use these arbitrary rotation periods, we can compute the longitude of the central meridian (C.M.) at any time, the C.M. being the imaginary line from pole to pole bisecting the disc. If, as is customary, this reference line is for the illuminated part of the disc, a small correction for phase is applied. We shall use the symbols λ_1 and λ_2 to represent, respectively, longitudes of System I and System II.

Programmes of colour and intensity observations, drawing and photography of the planet, and transit work are regularly possible means of observations. Colour and intensity work is described later, while it is sufficient to say that drawings and photographs have several applications in supplementing other programmes.

Transit work remains and deserves some note of explanation. Mr. B. M. Peek, Director of the Jupiter Section of the B.A.A., has ably discussed the importance of observing the changes which constantly take place in the atmosphere of the planet.[1] These changes consist not only of variations in the *form* of the usually ephemeral marks which are superposed on the fairly stable belt and zone system, but also of the drifts of these spots or marks in latitude and longitude—longitudinally with respect to System I or System II. Since changes in latitude are slight, we are nearly always concerned with changes in longitude. We consequently wish to determine the longitude of any mark as often as possible and over as great a period of time as possible in order to find the rotational drift in longitude and its possible peculiarities. Longitudes may be measured from good photographs or determined visually at the telescope with a filar micrometer; but the amateur usually employs a third and much simpler method, that of estimating visually when a mark is on the C.M. of Jupiter. Corresponding longitudes of such transit observations are then easily computed. The data thus accumulated are best studied by plotting the transit observations on charts of graph paper, longitudes against dates. From an examination of these charts, marks seen on successive dates can be

*See the *N.A.* or *Handbook* of the Brit. Ast. Assoc.

[1]References are given at the end of the paper.

identified, their drifts in longitude established, and their periods of rotation determined. Rotation periods then give us a basis for often profitable study of the planet.

The pioneer work of the late A. S. Williams in this field is well known, as is the work of the Jupiter Section of the B.A.A. in expanding it.

We should note here that, since the Jovian marks are usually symmetrical, their centres are often referred to in transit work; and unless otherwise mentioned, we mean the centre in giving the longitude of a mark. However, any definite point on it or its longitudinal extremities, termed the preceding and following ends, may be used also.

It may be questioned whether simple eye-estimates of transits of marks across the C.M. of Jupiter give sufficiently accurate determinations of longitudes. Peek has concluded that the expected error of a Jovian transit observation is about two or three minutes (1°.2 to 1°.8) and should rarely attain five minutes (3°.0)[1]. With some experience such degrees of accuracy can usually be obtained. It is evident that the accuracy of a derived rotation period is directly proportional to the length of time a mark is observed. If an error of five minutes is incurred in thirty days of observation, the resulting rotation period will be in error by four seconds. This represents about the maximum error in rotation periods for individual marks derived from observations made in the way under consideration.

General Appearance

The full disc drawing reproduced in Figure 2 and the photograph (without filter) by Wilson reproduced in Figure 3 show perhaps typical views of the planet, but a brief description of the general appearance of Jupiter during the apparition may be of value.

There were present six readily visible belts, more of those easily seen than there had been for several years. These belts were the N.Temp.B., the N.E.B., the E.B., the S.E.B.$_N$, the S.E.B.$_S$, and the S.Temp.B. Much lighter than the above six and distinguished only a few times in the polar shadings were the N.N.Temp.B. and

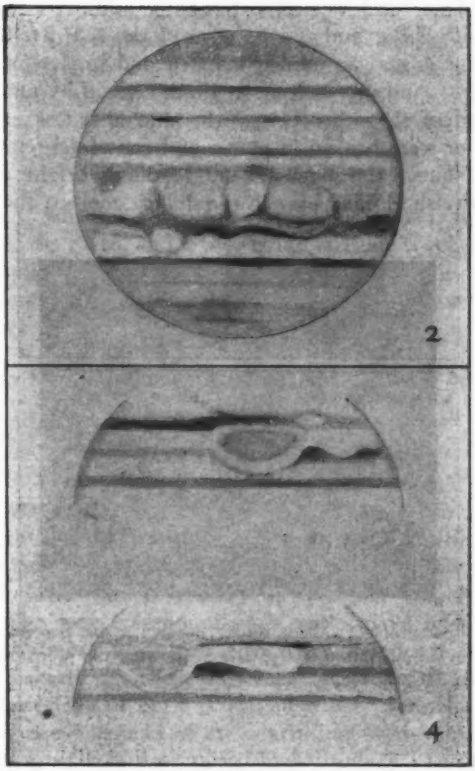

Fig. 2.—Drawing of Jupiter on November 9, 1939, 1h 10m U.T., by H. M. Johnson—$40°_1$, $236°_2$.

Fig. 4.—Sectional drawings of the S. Tropical region of Jupiter showing the Great Red Spot and S. Tropical disturbance, by H. M. Johnson. *Upper*, July 29, 1939, 8h 56m U.T., $150°_2$. *Lower*, August 18, 1939, 6h 30m U.T., $188°_2$.

the S.S.Temp.B. The northern and southern components of the S.E.B. were easily separated, and the E.B. lay very close to the $S.E.B._N$. This band was almost exactly midway between the S. edge of the $S.E.B._S$ and the N. edge of the N.E.B. The N.E.B. had irregular edges, was much knotted and broken up into dark condensations, and was at least at times crossed by numerous thin rifts. Most of the other belts either included less marked condensations or were broken in places and contained relatively dark sections. None of the zones was outstandingly bright; and in May the then grayish E.Z. was much the dullest zone on the planet (as

Fig. 3.—Photograph (without filter) of Jupiter on September 28, 1939, 6h 0m U.T., by L. J. Wilson—$62°_1$, $217°_2$—showing the preceding end of the South Tropical Disturbance.

it had been in 1938), but it had become a little lighter by October. As Figure 2 shows, there was in the E.Z. much detail, consisting largely of oval bright spots and dark wisps, with almost all the former placed along the S. edge of the N.E.B. These spots ranged in size from those comparable to the four large satellites to those extending twenty degrees in longitude and also varied considerably in brightness. The wisps may have been thicker and darker in July than later. The preceding ends of both spots and wisps were usually sharper than the following ends. In May and June the

N.P.R. was probably unusually large and dark, but by November it was smaller and lighter.

Latitudes. Of Wilson's 1939 photographs Johnson measured for latitude those of September 28, C.M. 62_1, 217_2; October 8, C.M. 139_1, 218_2; and December 18, C.M. 59_1, 317_2; all made without use of filters. The three selected images were each measured twice, the linear distance d from the centre of the image to the desired belt along the C.M. being obtained. Then

$$\sin |\beta - D\oplus| = d/R$$

approximately, where R is the polar radius, $D\oplus$ the planetocentric declination of the earth, and β the Jovian latitude (negative for the southern hemisphere). The quantity most difficult to obtain accurately was R, because of a diffused limb. We give the mean results below:

Belt	d/R	$\beta - D\oplus$	β
Middle N.Temp.B.	.391	+23°.0	+25°.5
N. edge N.E.B.	.237	+13 .7	+16 .2
S. edge N.E.B.	.076	+ 4 .4	+ 6 .9
Middle S.E.B.$_N$	.180	−10 .4	− 7 .9
Middle S.E.B.$_S$	.324	−18 .9	−16 .4
Middle S.Temp.B.	.509	−30 .6	−28 .1

Rotation Periods. We have already considered the method for studying rotation periods. In the preparation of the following tables of rotation periods for specific latitudinal currents, some 1200 transit observations, mainly by Johnson and Haas, were available. The first column of each table gives an identifying number to the mark for which a rotation period has been found The second column describes the character of the mark, whether bright or white (W) or dark (D)* and if the preceding end p or the following end f instead of the centre has been followed. The third column gives the longitude, in the appropriate System, of each mark at opposition if its drift was seen to extend through that date. All marks in a current are listed in order of increasing longitude from the zero meridian of the System to which they belong. The fourth column gives the dates on which the first and last transit observations of the mark were obtained. These dates do not necessarily denote the limits of its life, because of the

*Present knowledge of Jupiter really does not allow further useful and concise physical identification.

impossibility of complete thoroughness in observing the whole surface, but in some cases do indicate these limits. The fifth column shows the computed rotation period of each mark; for each current a mean of these individual rotation periods is given.

In a few cases uncertainty exists as to proper identification and correlation of the transit observations going to form a drift. However, we believe that the rotation periods here published are substantially correct. We style our presentation after the excellent system used in B.A.A. *Memoirs* on Jupiter. Those rotation periods which have been found from observations by only one member of the group are so indicated by the initial of the last name of that observer.

TABLES OF ROTATION PERIODS

N.P.R. (or N.N.N.Temp.B.)

	Description	λ°_{2} ☌	Dates	Rotation Period	
1	D	—	Nov. 22—Jan. 21	9h 55m 21s	*J*
2	D	142	July 29—Dec. 31	9 55 13	*J*

Mean 9h 55m 17s

N.N.Temp.B.

	Description	λ°_{2} ☌	Dates	Rotation Period	
1	D*p*	37	July 19—Nov. 22	9h 55m 30s	*J*
2	D	305	Sept. 27—Dec. 29	9 55 28	*J*

Mean 9h 55m 29s

N.Temp.Z. and N. edge N.Temp.B.

	Description	λ°_{2} ☌	Dates	Rotation Period	
1	D	86	July 9—Dec. 9	9h 56m 0s	

N.Trop.Z. and N. edge N.E.B.

	Description	λ°_{2} ☌	Dates	Rotation Period	
1	D*f*	—	July 14—Aug. 9	9h 55m 22s	*J*
2	W	—	July 9—Aug. 9	9 55 20	
3	D	—	Aug. 15—Sept. 10	9 55 30	*J*
4	D*f*	214	July 3—Dec. 29	9 55 25	*J*
5	W	226	Sept. 21—Dec. 29	9 55 24	
6	D	—	July 14—Aug. 29	9 55 20	

Mean 9h 55m 24s

S. edge N.E.B. and N. part E.Z.

	Description	λ°_{1} ☌	Dates	Rotation Period	
1	W	—	June 30—July 27	9h 49m 54s	*J*
2	D	—	July 9—Sept. 4	9 50 29	
3	W	13	June 30—Oct. 14	9 50 21	
4	D	22	June 28—Oct. 17	9 50 23	
5*a*	W	—	June 30—Aug. 3	9 50 10	*J*
6*a*	W	—	July 7—Aug. 4	9 49 55	*J*
7	D	—	Aug. 18—Sept. 21	9 50 19	
8	W	42	July 16—Dec. 22	9 50 24	
9	D	60	July 14—Oct. 7	9 50 21	

	Description	$\lambda^{\circ}{}_{1}$ ☌	Dates	Rotation Period	
10	D	70	July 23—Dec. 31	9 50 22	
11	W	82	July 14—Oct. 15	9 50 24	
12*b*	W	—	July 19—Aug. 29	9 50 19	
13	D	97	Aug. 29—Nov. 30	9 50 14	
14	W	—	Oct. 1—Jan. 1	9 50 24	
15	W	—	July 1—Aug. 29	9 50 21	
16*c*	W	—	July 3—Aug. 18	9 50 12	
17	D	—	Aug. 18—Sept. 22	9 49 51	*H*
18	W	138	Aug. 27—Dec. 29	9 50 16	
19	D	148	June 29—Oct. 1	9 50 12	
20	D	164	Sept. 22—Dec. 9	9 50 28	
21	W	183	June 29—Jan. 22	9 50 23	
22	D	—	July 8—Aug. 4	9 50 12	
23*d*	D	206	July 8—Dec. 9	9 50 18	
24	W	214	July 8—Dec. 25	9 50 20	
25	W	—	Dec. 3—Dec. 26	9 50 30	
26*e*	W	—	June 18—Aug. 9	9 49 43	
27	D	—	Aug. 9—Sept. 10	9 50 20	
28*f*	W	—	June 7—Sept. 16	9 50 2	
29	W	267	Aug. 28—Nov. 1	9 50 15	
30	D	276	Sept. 6—Dec. 26	9 50 14	
31	W	—	Oct. 14—Dec. 26	9 50 17	*J*
32	W	—	July 2—July 29	9 49 57	*J*
33*d*	D	300	July 11—Feb. 12	9 50 19	
34*d*	W	317	July 16—Feb. 10	9 50 21	
35	D	—	June 23—Sept. 23	9 50 19	
36	D	343	Aug. 21—Dec. 22	9 50 19	
37	W	353	Aug. 21—Dec. 10	9 50 21	

Mean 9h 50m 15s

a Coalesced.
b Same as 14?
c Coalesced with 15 in mid-August?
d Part of drift very sinuous.
e Coalesced with 24 in mid-August?
f Early part of drift uncertain.

S. part of E.Z. and N. edge S.E.B.N.

	Description	$\lambda^{\circ}{}_{1}$ ☌	Dates	Rotation Period	
1	D*f*	—	Sept. 28—Dec. 29	9h 50m 27s	*J*
2	D	—	Aug. 13—Sept. 14	9 50 29	
3	D*f*	—	July 14—Aug. 4	9 50 22	*J*
4	D	—	Aug. 3—Sept. 10	9 50 30	*J*
5	W	—	Aug. 3—Sept. 3	9 50 42	
6	D	—	Aug. 15—Sept. 24	9 50 34	*J*
7	D	—	July 19—Aug. 15	9 50 33	*J*
8	D	—	Aug. 4—Sept. 27	9 50 27	*J*
9	D*f*	—	Dec. 2—Jan. 22	9 50 24	*J*
10	D*p*	—	Nov. 1—Nov. 21	9 50 30	*J*
11	D	—	July 6—July 27	9 50 32	*J*
12	D	—	July 6—July 22	9 50 40	*J*
13	W	—	Oct. 7—Dec. 3	9 50 38	
14	D	—	Sept. 28—Dec. 31	9 50 25	

Mean 9h 50m 31s

N. edge S.E.B.S.

	Description	$\lambda^{\circ}{}_{2}$ ☌	Dates	Rotation Period	
1	D	—	July 9—Aug. 4	9h 55m 45s	*J*
2	D	—	Nov. 21—Dec. 31	9 55 45	*J*

Mean 9h 55m 45s

Great Red Spot

	Description	$\lambda^{\circ}{}_{2}$♂	Dates	Rotation Period
1	Centre	163	July 7—Jan. 22	9h 55m 43s

Great Red Spot Hollow

	Description	$\lambda^{\circ}{}_{2}$♂	Dates	Rotation Period
1	*p* end	145	June 6—Dec. 9	9h 55m 44s
2	Centre	160	June 30—Jan. 22	9 55 43
3	*f* end	173	June 6—Dec. 22	9 55 44

Mean 9h 55m 44s

S. Tropical Disturbance

	Description	$\lambda^{\circ}{}_{2}$♂	Dates	Rotation Period
1	*p* end	205	July 3—Dec. 13	9h 55m 35s

S.Temp.B and S.Temp.Z.

	Description	$\lambda^{\circ}{}_{2}$♂	Dates	Rotation Period	
1	D	—	Oct. 14—Jan. 6	9h 55m 30s	*J*
2	D	—	Oct. 5—Dec. 25	9 55 31	*J*
3	D	131	July 29—Dec. 26	9 55 7	*J*
4	D	154	July 29—Nov. 22	9 55 10	*J*
5	D	178	Sept. 9—Oct. 13	9 55 3	*J*
6	D*f*	—	Nov. 21—Dec. 29	9 55 18	*J*
7	D	—	Oct. 14—Dec. 29	9 55 23	*J*
8	D	—	Oct. 14—Dec. 3	9 55 37	*J*

Mean 9h 55m 20s

Descriptive Notes.—We here expand upon some other particulars of the various currents.

N.P.R. The southern boundary of this polar region seemed to vary between the N.N.Temp.B. and N.N.N.Temp.B. The belt forming this boundary was simply a darkening at the edge, and the two indefinite dark objects observed for rotation periods formed in turn on its northern edge, thus perhaps belonging to the N.N.N.Temp.B. The short rotation period appears well founded.

N.Temp.Z. and N. edge N.Temp.B. The rotation period for the one object seen here is about normal. This object was of interest not only because of its solitude but also because of its intense blackness, which for a time made it the darkest mark on the planet. It was elongated and perhaps touched the N. edge of the N.Temp.B., although in the N.Temp.Z.

N.Trop.Z. and N. edge N.E.B. Of great interest were some small projections from the S. edge of the N.Temp.B. having an extremely short rotation period (which has previously manifested itself in this current). They were first confirmed by B. M. Peek in early October, and he has given an account of B.A.A. observations of them in which he finds a mean rotation period of 9h 48m 56s for 11 of them.*

Other detail in this current ordinarily consisted of white spots and of darkened condensations at the N. edge of the N.E.B. or elongated dark streaks lying in the S. part of the N.Trop.Z. and detached from the N.E.B. except at their preceding ends. The six objects for which rotation periods are given were the

*Early 1940-41 apparition observations show that they have survived.

only ones certainly identified for drifts and constitute about a third of the marks seen.

S. edge N.E.B. and N. part E.Z. Usually this region is the most detailed and interesting on the planet. In 1939-40 the northern part of the E.Z. was quite active; but though certain regions were too turbulent to exist long enough to give rotation periods for our table, other marks (such as Nos. 21, 23, 24, 33, and 34) endured for long periods. Even the long-lasting marks, however, underwent sometimes much change in aspect and period of rotation. Because of the number and wide distribution of marks, the mean rotation period given is probably nearly exact; if not, it may be slightly short because of the inclusion of certain rather short-lived marks having rapid motions.

S. part E.Z. and N. edge S.E.B.$_N$. This current was an even more unstable part of the planet than the preceding. Identification of marks here in successive transit observations was somewhat uncertain, and only part of the observations made could be used effectively in obtaining rotation periods. Most of those used, moreover, were not for a long enough time to give good individual rotation periods, but it is thought that the mean is close. The difference between the northern and southern parts of the E.Z. in regard to period of rotation should be noted.

N. edge S.E.B.$_S$. The few observations for these two faint objects give this current the second longest period of rotation on the planet.

S.Trop.Z. No other objects besides the Great Red Spot (R.S.) and Hollow (R.S.H.) and South Tropical Disturbance (S.Trop.D.), to which a following section of this paper is devoted, were recorded for drifts in this zone.

S.Temp.B. and S.Temp.Z. A dull white spot in the S.Temp.B. encroaching on the following end of the R.S. was seen but for too short a time to obtain a rotation period. In August the N. edge of the S. Temp.B. was darkened in the longitudes between the R.S.H. and the S.Trop.D., especially so *at* the preceding end of the Disturbance. Condensations in the S.Temp.B., projections from its south edge, and larger indefinite dark areas in the S.Temp.Z. afforded rotation periods the mean of which should be close for this current. In early September a very fine belt had formed slightly north of the middle of the S.Temp.Z following two dark areas and in the longitudinal region embraced by the R.S.H.

The Great Red Spot and the South Tropical Disturbance—1936-1939

The Great Red Spot of Jupiter, situated in the S.Trop.Z., has been a wel known mark since its startling appearance in 1878. Beginning as a deep red spot on the planet, the mark has since passed through many variations in aspect and has suffered changes in its period of rotation, though usually its rotation period has been shorter than that of System II. When the R.S. itself is not strong, its position is indicated by its accompanying Hollow which forms a bay or notch in the S.E.B. as a result of an apparently *repelling* force of the R.S. on immediately surrounding matter. In 1901 there developed in the S.Trop.Z. another disturbance which has lasted to this time and which has been called the South Tropical Disturbance. It is of different character from the R.S., however,

having developed from a small dark spot at discovery to a large area darkening a major section of the S.Trop.Z. It, too, passes through variations, at times disappearing. An excellent summary of the complex inter-relations between it and the R.S. from 1901 to 1933 has been given by Rev. T. E. R. Phillips.[3] We shall here discuss some of the more important points concerning these two marks during the last four apparitions.

1936. The R.S. was a darkly reddish, elongated spot somewhat lightened in its centre and well contrasted against the especially white S.Trop.Z. The R.S.H. was effaced by the absence of the S.E.B.$_S$. The longitudinal drift as shown by five observers from March to September has been discussed by E. P. Martz, Jr.[4]; he found a nearly stationary longitude near $\lambda_2 143°$ at opposition on June 10. The S.Trop.D. was not seen.

1937. The S.Trop.Z. attained a very bright white tone, and the S.E.B.$_S$ again was not seen, leaving the R.S. as an isolated spot about twenty-three degrees long, much as in 1936. Haas noted on June 30 that the R.S. was separated from the S.Temp.B., where it had previously appeared joined. About 40 transit observations by Haas and Johnson and a number by Wilson, from May to November, again gave the R.S. a nearly stationary longitude which at opposition on July 15 was $\lambda_2 141°$. The resulting rotation period between the 1936 and 1937 oppositions is 9h 55m 40.4s. The S.Trop.D. failed to reappear.

1938. Between the 1937 and 1938 apparitions the S.Trop.Z. dulled, the R.S. disappeared and was instead represented by the light oval of the R.S.H., and the S.Trop.D. appeared distinctly. Such a transformation, though remarkable, is not entirely uncommon. Along with these changes in appearance was an unusual rotational deceleration of the R.S.H. (or, what can be considered practically synonymous for this purpose, the R.S.). The Hollow therefore was at $\lambda_2 147°$ at opposition on August 21. The rotation period between the 1937 and 1938 oppositions was hence 9h 55m 41.2s. The preceding end of the S.Trop.D. was at $\lambda_2 269°$ at opposition, and gave a rotation period of 9h 55m 37s during the apparition.

1939. Between the 1938 and 1939 apparitions the R.S. region had again changed in aspect. The southern component of the S.E.B. was deflected northward at the R.S. to the degree of tangency with the S.E.B.$_N$, forming the R.S.H. in a different way than in 1938. The bending points or "shoulders" formed by the deflection of the S.E.B.$_S$ marked the ends of the R.S.H., for this region was in 1939 little whiter or brighter than surrounding portions of the S.Trop.Z. The R.S. itself was a rather faint, roughly elliptical stain about twenty-one degrees long, the faintness being especially evident early in the apparition. In fact, Haas did not see it on June 6 using the Case 9-inch refractor; and the writers first noted it with Johnson's 8-inch reflector on June 30. The colour of the R.S. was neutral or reddish gray. The R.S. region is represented in figure 4.

In 1939 the S.Trop.D. was fainter and less turbulent than in 1938. Since the preceding apparition the normally decreasing longitude of the Disturbance had brought its preceding end to $\lambda_2 206°$ when first seen on July 3, but its drift thereafter can hardly be considered normal. A drawing by Wilson on June 16,

C.M. 205°$_2$, failed to show the Disturbance. Almost 200 transit observations were used to prepare the graphs of the preceding end (p), centre (H), and following end (f) of the R.S.H.; the graph of the centre (S) of the R.S.; and the graph of the preceding end (D) of the S.Trop.D., all of which are shown in figure 5. First, note thereon that the centres of the R.S. and R.S.H. do not coincide longitudinally, the mean residual for the apparition being about three degrees. Whether this difference was real or subjectively caused by a darkening of the following portion of the R.S. is uncertain. Second, an inspection of the graphs

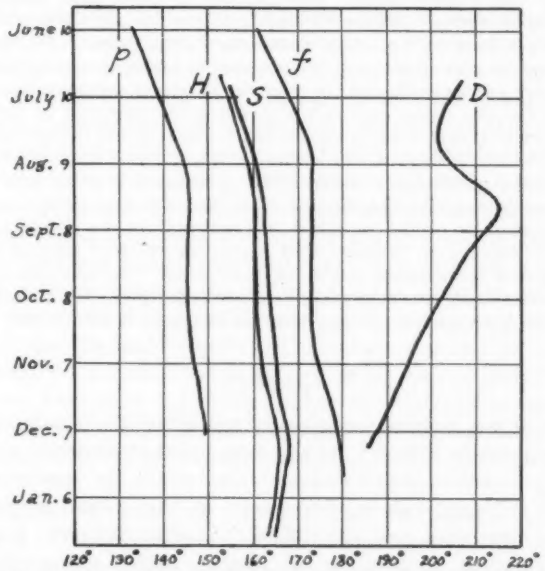

Fig. 5.—Graphs of the longitudinal drifts of the Great Red Spot, Red Spot Hollow and S. Tropical disturbance in the 1939-40 apparition.

shows that at opposition the longitude of the R.S.H. was $\lambda_2$160°, demonstrating a continuation of the unusal deceleration which began in 1936-1937 and which gave between the 1938 and 1939 oppositions a rotation period of 9h 55m 41.9s —perhaps the longest of lasting character in the mark's life.* Third, some apparent correlations between the R.S.H. and S.Trop.D. drifts and certain observed phenomena in their region require attention. The early portions of graphs H and D show nothing unexpected, and the short section of the S.Trop.Z.

*Early 1940-41 apparition observations indicate the deceleration has been fairly well sustained.

between the R.S.H. and the preceding end of the S.Trop.D. was of ordinary brightness. But in late July there developed in the S.Trop.Z. slightly preceding the S.Trop.D. a very white and bright area. At the same time we see by graph D that the Disturbance began to be greatly decelerated, while the S. edge of the S.E.B.S. was depressed as is shown in figure 4. At mid-August we find also some evidence that the R.S.H. was accelerated shortly, perhaps only at the following end as an act of shortening. About the end of August the deceleration of the Disturbance expired, and thereafter the more usual course of decreasing longitude was followed again. Interpretation of these large changes must necessarily be uncertain, but there is much to support the suggestion of some kind of expansive force in the bright white area during August. Certain points concerning the relative effects of the proposed "expansion" on the Hollow and Disturbance longitudinally and the difference in time of maximum effect on the drifts of the two marks need further investigation than can be given here. Fourth, graph D shows that a conjunction of the R.S. and S.Trop.D. possibly occurred by late December, and in late January Johnson suspected that faint dark material preceded the former. This observation, together with the last part of graph H, would seem to confirm previous B.A.A. work showing an apparent acceleration of *both* the R.S.H. and S.Trop.D. at the time of their conjunction. Between the 1938 and 1939 oppositions we find a rotation period of 9h 55m 34s for the preceding end of the Disturbance. The following end of the Disturbance was not seen at any time here, but Peek reports B.A.A. observations of it in the latter part of the year when its longitude decreased from $\lambda_2 60°$ to $\lambda_2 48°$.[2]

Colours

One of the writers has already published the results of their colour-studies in 1936-8.[5] It was found that obstacles to attaining accuracy in colour-observations of Jupiter are the absence of any area of standard colour, differences in the colour-judgment of different observers, and the difficulty of describing the hues consistently when attempting to detect slight variations. The interested reader is referred elsewhere[6] for a more complete discussion of the intrinsic difficulties of colour-work.

Between June 29 and August 21 Haas made 339 colour estimates; and between April 26 and December 25 Johnson made 65 such observations, all but five coming on October 15 or later. With a few exceptions, both observers used exclusively in this work an 8-inch reflector at 213X and worked only in a clear and dark sky. Haas employed as colour filters in all observations Eastman Kodak Company Wratten Filters 25 (red), 47 (blue), and 58 (green); Johnson used no filters.

The two temperate belts, the N.E.B., and both components of the S.E.B. all possessed during the whole apparition a reddish or coppery colour. The hue was less marked to Johnson, who often thought the belts rather brown, than to Haas. With the exceptions that the S.Temp.B. was more red in August and later than in July, when it was often merely tinged with red, that the N.Temp.B. may have been more red in October-December, when Johnson observed it to be the reddest belt on the planet, than in July-August, none of the belts exhibited any consistent tendency toward either increasing or decreasing redness during the entire apparition. However, it is probable that the individual belts varied in colour from date to date and also at different longitudes on the same date. Such short-period changes appeared to occur rather frequently over periods of a few weeks and perhaps occasionally in only a few days. We exemplify the statement just made: On December 8 and 11 Johnson found no appreciable red in the N.Temp.B. near $\lambda_2 50°$, but he described this belt near $\lambda_2 75°$ as "very dark red" on December 25. Haas observed the S.Temp.B. near $\lambda_2 220°$ to be "reddish gray" from July 8 to July 22, nearly gray (no appreciable red) on July 27 and 30, and "copper red" on August 9 and 18. Johnson described the S.E.B.$_S$ near $\lambda_2 50°$ as "dark brown slightly tinged by red" on December 8 but as "light red" only three days later. Considering the belts at all longitudes and during the entire apparition, the S.Temp.B. was less red than the other four, which were of similar hue.

The N.P.R. was gray in 1939, and the S.P.R. was slightly purplish. The colour of the southern shading probably was of the unstable nature which we have noted in the conspicuous belts.

The tropical zones were white. Although as dull as in 1938, the E.Z. in May was no longer tawny but rather was grayish. In July it was lighter, being dull white; and in August it may have been still lighter. The two writers independently noted that the space between the S.E.B. components was bright yellow in the first ten days of July. From July 10 to August 20 this yellow slowly faded into white, but tinges of yellow were remarked by Haas at some longitudes as late as August 18. Johnson considered this zone to be yellowish on November 5 but not sensibly different from the perhaps dull purplish of the S.Trop.D. on December 21.

The late A. S. Williams, from a study of observations by himself and others, found that the equatorial belts exhibit a periodic and apparently seasonal variation in colour.[7] When the N.E.B. is darkest and reddest, then the S.E.B. is lightest and gray or even bluish; and conversely. Williams derived empirically the formula Standard Epoch (maximum redness S.E.B.) $= 1838^{y}.52 + 11^{y}.86E$, and this formula would place the next S.E.B. maximum at 1945.3. Observations by Haas would indicate that the S.E.B. was at its minimum redness in 1937, rather earlier than prediction; but it will still be of interest to see whether the S.E.B. actually reddens and darkens and the N.E.B. fades during the next few years.

Relative Intensities of the Belts

In order to obtain a record of the darknesses and changes of darkness of the belts, Haas made 118 sets of estimates of the relative intensities of the belts between May 1 and January 10. The other observers supplied some notes on this subject. To secure from such data a true record of the changes in intensity of the belts is made difficult by several causes:

1. A belt may be darker (more intense) in some parts of the planet than in others.

2. Since marks moving in System I rotate once in about 47 days with respect to those in System II, we see, bearing in mind the first cause, that it may be misleading to compare belts moving in different Systems, except in observations only a few days apart.

3. When two belts at first different in intensity are later in some other different ratio of darkness, one cannot tell whether one has darkened or the other has lightened or both things have happened.

4. As in all planetological work, certain variations in appearance are to be expected as the seeing, the clearness, the magnification, and the telescope are altered; but it is felt that when dealing with detail as prominent as Jovian belts, such errors are unimportant.

5. A belt which is really very dark but very narrow may be apparently much lightened in poor seeing when the planet's details are vibrating considerably.

These difficulties were augmented in 1939-40 by the fact that

the several most conspicuous belts often were all of nearly equal intensity.

In the description to follow we shall, for the most part, speak of the darknesses of the belts *averaged over all longitudes*; and hence the order in intensity we give was not necessarily the actual order on any particular date.

In May and June, while the planet was seen only on a dawn sky under rather poor conditions, the N.E.B. and S.E.B.$_S$ were definitely the darkest belts. The latter was the darker near $\lambda_2 200°$; the former, elsewhere. Somewhat lighter than these two belts and about equal to each other were the S.E.B.$_N$ and the N.Temp.B., the latter being more marked in June than in May. Much lighter still were the S.Temp.B. and the E.B.

In July the N.E.B. and the N.Temp.B. had interchanged places. During this month the S.E.B.$_S$ darkened somewhat relative to other belts and was the darkest belt on the planet from $\lambda_2 180°$ to $\lambda_2 290°$. It was, however, fourth or fifth near $\lambda_2 100°$. The first four belts were about equal in darkness. Much lighter than any of these was the S.Temp.B., which but slightly surpassed the E.B.; much the lightest of all were the N.N.Temp.B. and the S.S.Temp.B. The N.N.Temp.B. was seen more often and was slightly darker than the S.S.Temp.B., but both were difficult. The three belts named last showed no plausible variations in darkness subsequently and will not be again mentioned; the E.B. almost always came just after the five most conspicuous belts.

In August the belts were the same darkness as in June, except for the S.E.B.$_S$ and the S.Temp.B. The former was the darkest belt on the planet from $\lambda_2 180°$ to $\lambda_2 0°$, and the preceding half of this section was much darker than any other belt. As before, this belt gradually lightened as one observed it from $\lambda_2 180°$ to $\lambda_2 140°$ and had faded to fifth rank at $\lambda_2 90°$. The R.S.H. formed the break between the light and dark terminations. The S.Temp.B. grew somewhat darker than it had previously been.

In September the darkening S.Temp.B. became equal to the N.Temp.B., but things were otherwise much as in August. In October the S.E.B.$_S$, then equal in darkness at all longitudes, faded and by November had become the faintest of the five chief belts. The S.E.B.$_N$ was the darkest belt on the planet for a short time in early October, as was the N.Temp.B. in early November. The

S.Temp.B. continued to darken slowly from October to December. In December and January the N.E.B. was the darkest belt on the planet.

In addition to the gradual changes just described, the belts exhibited alterations in short periods of time, of which we give three examples: On August 9 near $\lambda_1 265°$, $\lambda_2 80°$ the order in intensity of the first five belts was N.E.B., S.E.B.$_N$, S.Temp.B., N.Temp.B., and S.E.B.$_S$. The next night the S.E.B.$_N$ and N.Temp.B. were about equal and darkest; then came the S.E.B.$_S$ followed by the nearly equal N.E.B. and S.Temp.B. Though lighter than the S.E.B.$_N$, S.Temp.B., or N.Temp.B. near $\lambda_1 150°$ on August 14, the N.E.B. there surpassed all of those belts on August 18. Near $\lambda_2 160°$ the N.Temp.B. on September 3 surpassed the S.Temp.B., the S.E.B.$_S$, and the S.E.B.$_N$; but on September 6 it was lighter than any of them.

These rapid changes in both colour and intensity of the belts are evidence of violent activity of some sort on an extremely large scale in the planet's atmosphere.

Plea for Observers

It is evident that observations of the active planet Jupiter in any of the fields suggested in this paper can hardly become too abundant, both for thoroughness and for elimination of personal bias. Therefore, the writers wish to express their desire to hear from observers able to engage actively in this interesting work, even though they possess only moderate equipment. It must also be borne in mind that American work, always comparatively small in planetary fields, may become increasingly important in the future.

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THE INTERSTELLAR ABSORPTION LINES OF MOLECULAR ORIGIN

By P. SWINGS

RECENT observations by W. S. Adams at the Mount Wilson Observatory have brought conclusive evidence of the existence of molecules in interstellar space. Using very high dispersion and fine-grained plates, Adams discovered several sharp, interstellar lines due to *CH* and *CN*. It is rather interesting to notice that the conclusive evidence in favour of interstellar molecules came through the detection of sharp lines, whereas some years ago molecules had been considered in an attempt to explain the broad, interstellar features discovered by P. W. Merrill. Because of the importance of this problem, it seems worth while to summarize the various investigations which have recently culminated in Dr. Adams' startling discovery and to describe the present state of the problem of interstellar matter.

For a long time the H and K lines of Ca^+ and the principal lines of *Na* (D_1, D_2 and the ultraviolet pair) remained the only observed stationary lines. In 1934, Merrill (1) reported the discovery of four interstellar lines in the yellow and red regions of the spectrum; the wave lengths of these lines are λλ5780.4, 5796.9, 6283.9 and 6613.9; instead of being narrow and sharp, they are somewhat widened and have rather diffuse edges; no identification was found for these lines (2). Since the ultimate lines of all the abundant atoms and ions are now thoroughly known and since none of them coincides with any of Merrill's lines, H. N. Russell (3), in his George Darwin Lecture of 1935, suggested that they may rather be molecular bands; the fuzzy character of the lines adds some weight to this hypothesis. Russell concludes: "If the temperature of the gas is low enough—more precisely if the rotation of the molecules is little excited—only a few of the band lines observed at room temperature might appear."

This suggestion was developed by the author in 1936 (4). Assuming that the distribution on the rotational levels of the molecules is mainly due to selective absorption between these levels, and adopting a distribution of stars similar to the one considered by A. S. Eddington (5) in his discussion of interstellar ionization, the

order of magnitude of the "equivalent temperatures T_λ" (6) was determined for the rotational levels. For a given molecule, we actually have to determine the equivalent temperatures corresponding to the pure rotational levels; the rotational lines are always in the far infra-red, depending upon the moment of inertia I of the molecule. For example, for CO_2 ($I = 70.10^{-40}$g.cm.$^{+2}$), the first ten rotational lines go from about 10,000μ to 1000μ. The equivalent temperature turns out to be very low and for $\lambda = 1000\mu$, it is only 0.5°K.

In order to get some idea of the maximum width of a molecular band, the molecule of CO_2 was considered and a Boltzmann distribution was computed for $T_\lambda = 10$°K, $T_\lambda = 5$°K and $T_\lambda = 3.2$°K. The calculation shows that the number of observable rotational lines must be very small; for $T = 3.2$°K, which is still much too high, only the first three or four rotational lines would appear in the bands, which means that the widths of these bands would be less than 6 or 7 cm.$^{-1}$, or approximately 2A near λ6000; the edges must be diffuse. This was of the type observed by Merrill; in any case, it removed the objection that Merrill's lines, though fuzzy, are not broad enough to be of molecular origin (7).

These considerations had been applied to the example of the CO_2 molecule because a coincidence of wave-length had been observed between two of Merrill's lines and two calculated rotatory-oscillation bands of CO_2. This was, of course, a purely tentative identification, intended to illustrate the general problem; it could be verified by searching for the two stronger CO_2-bands at $\lambda\lambda$7820-7833 characteristic of the Venus spectrum. Subsequent observations by Merrill (8) and also theoretical considerations (9) showed that the coincidence was probably accidental.

When we consider the populations of the rotational levels, two cases are possible, depending upon the existence or the absence of an electric dipole in the normal electronic state of the molecule. In the first case (*CH*, *CN*, etc.), there are strong, selective transitions between the rotational levels (pure rotation spectrum), whereas in the second (H_2, O_2, N_2, . . .), these transitions are forbidden. But, owing to the very low density of interstellar matter, it was suggested that even a symmetrical molecule without electric dipole, may be able to emit these "forbidden" low-frequency radiations because

they occur faster than the exchanges of collisional processes. Hence a low temperature for the distribution of the rotational quantum numbers is appropriate in most cases; this point will be considered further on. It was also suggested that, once the identifications are certain, the determination of the intensities of the rotational lines will give a direct measure of the temperatures corresponding to the actual distribution on the rotational levels.

Simultaneously with this paper, Th. Dunham, Jr. and W. S. Adams reported their remarkable observation of interstellar *Ti II*-lines (10). The ground term of *Ti II* is a^4F; but only those transitions which arise from the lowest sub-level, $a^4F_{3/2}$, were observed, whereas the stronger lines arising from the higher sub-levels $a^4F_{5/2,\ 7/2,\ 9/2}$, were absent; $a^4F_{5/2}$ is only 0.012 volt above $^4F_{3/2}$. This important observation gave definite evidence that the forbidden transitions between the sub-levels of ^4F must occur in interstellar space ($\lambda\lambda 76\mu$, 103μ and 59μ). The magnetic dipole probabilities for these transitions are such that the lifetimes of $^4F_{5/2,\ 7/2,\ 9/2}$ are still shorter than the intervals between two collisions or absorptions. Practically all the Ti^+ atoms are in their lowest electronic sub-level. This conclusion concerning atomic levels is similar to the previous suggestion concerning molecular rotational states.

Almost simultaneously, Dunham (11) presented evidence for the presence of interstellar *Ca* I (λ4227) and *K* I (λ7699) and the Mount Wilson observers also recorded several sharp, unidentified interstellar lines at $\lambda\lambda$3934.3, 3957.7, 4232.6 and 4300.3A.

At this stage—in 1937—the unidentified interstellar absorption features were:

a) several broad lines between λ5780 and λ6614;

b) four sharp lines in the photographic region.

In 1937, M. N. Saha (12) published the statement that one of Merrill's bands (λ6283) was certainly due to the Na_2 molecule ($^1\Sigma \leftarrow\!- {}^1\Sigma$; $v''=0$, $v'=11$) and that another line (λ5780) might provisionally be attributed to *NaK* ($v''=0$, $v'=5$). This identification was criticized by Swings and Rosenfeld (13) and Eyster (14) for spectroscopic reasons. If Saha's identifications were correct, several other bands of Na_2 and *NaK* should be present and should even be stronger, according to the Franck-Condon diagrams of these two molecules.

The note by Swings and Rosenfeld contains two suggestions which proved to be fruitful later on. The first one concerns the estimation of the molecular abundances in interstellar space; the second deals with the identification of the sharp line λ4300.3 with *CH*. Assuming that the density of radiation in the region of molecular absorption leading to dissociation is identical with black-body radiation at temperature T diluted by the factor δ, the number of diatomic molecules in dissociative equilibrium will be given by the usual formula, except that the numbers of atoms have to be divided by $\sqrt{\delta}$. Applying this, for example, to the *CH*-molecule with $T = 10{,}000°K$ and $\delta = 5.10^{-15}$, it is found that the number of *CH*-molecules per cubic centimeter is (15)

$$n_{CH} \sim 10^{-8} n_C n_H.$$

Application to CO_2 and Na_2 shows that the abundance of these molecules is probably much too low to permit detection in interstellar absorption. The molecular abundances were then compared to the atomic abundances. It may safely be assumed that the atomic populations of *H*, *O*, *N* and *C* per cm.^{3} are between 1 and 10^{-3}. Thus, for diatomic compounds such as H_2, (16) *OH*, *CH*, *NH*, O_2, *CO*, *CN*, etc., the numbers of molecules would not be much smaller than the numbers of observed interstellar atoms. In other words, a search for the interstellar bands of *CH*, *OH*, *NH*, *CN*, C_2, ... seemed most promising. In 1937, only one coincidence was available and it was pointed out by Swings and Rosenfeld (17); they suggested that the sharp interstellar line observed at λ4300.3 may be due to *CH*. The absorption lines of *CH* starting from the two lowest rotational levels of the ground electronic and vibrational state are λ4300.24 and λ4303.86. If the second line were present, it would be blended in an early B-star with OII 4303.82 and this might prevent its detection. In any case (18), "the first would give an interpretation of the interstellar line observed by Dunham; the corresponding absorbing molecules would all be in their lowest level, in complete analogy with the case of Ti^+-atoms."

The theoretical treatment of the dissociation equilibrium under interstellar conditions of extreme dilution was only a first approach to the problem; a revised, detailed theoretical investigation of this most interesting case is now required and is planned at the Yerkes Observatory.

At the Astrophysical Symposium on Interstellar Matter, held in Paris in 1937, the molecular problem was discussed in some detail (19). Let us assume that the molecule has a permanent electric dipole and let us compute the equivalent temperatures T_λ for the infra-red regions, where the pure rotation spectrum is located. We easily find the following data:

TABLE I. Equivalent Interstellar Temperatures for $\lambda > 1\mu$

λ	T_λ	λ	T_λ
1μ	414° K	100μ	5.0° K
5μ	81.2	500μ	1.0
10μ	47.0	1000μ	0.54
50μ	9.3	10000μ	0.06

We are trying to find under which conditions will there be an appreciable population on a certain rotational level which can be reached by absorption of wave length λ. For example, when shall we have

$$e^{-\frac{h\nu}{kT_\lambda}} > e^{-1} ?$$

This requires $\lambda T_\lambda > 1.5$ c.g.s. or $\lambda T_\lambda > 1.5 \times 10^4$ micron-degrees. If we adopt the figures of Table I, we find that between 1μ and $10{,}000\mu$, the product λT_λ is practically constant, around 500 micron-degrees. This means that, whatever λ, the population on the rotational level would be very low and we should thus expect to find practically all the molecules in the lowest rotational level.

The crude character of this treatment is evident, especially because of the method of determining T_λ. It is improbable that T_λ is constant in space and that it behaves as simply and regularly as was assumed for the computation of Table I. It is quite possible that in certain regions of space or of wave-lengths, T_λ is such that λT_λ varies and may become greater than 1.5×10^4.

If, instead of absorptions, the collisions (which are very rare) were responsible for the excitation of molecules in their rotational levels, the excited molecules would almost always have time to fall down to a lower rotational level, with emission of permitted or forbidden lines, depending upon the presence or the absence of an

electric dipole. The question is quite similar to the case of the ground sub-levels of ionized titanium discussed by Dunham.

In 1938, C. S. Beals and G. H. Blanchet (20) discussed their observations of a diffuse, broad, symmetrical band, extending from λ4410 to λ4450, which had been noticed previously by Merrill as a vague feature near λ4427. The important work by Beals and Blanchet gave definite evidence in favour of an interstellar origin. This was also confirmed by Miss F. Sherman (21).

The situation had thus become the following: although interstellar molecules had been initially considered for the explanation of fuzzy bands, it now appeared that they would rather give an interpretation of the sharp unidentified lines. The recent observation of new sharp lines by Adams improved the situation considerably. A few months ago, Adams (22) reported the observation of a new faint, sharp line in the spectrum of ζOphiuchi at λ3874.6 and McKellar (23) noticed its coincidence with the R(0) line of the (0, 0) band of *CN* ($^2\Sigma \leftarrow\!- {}^2\Sigma$) at λ3874.61. McKellar also noticed that the sharp line λ3934.3 coincides with the R(0) line of the (9, 0) transition in *NaH* ($^1\Sigma \leftarrow\!- {}^1\Sigma$) at λ3934.29; this identification is subject to doubt (24), and McKellar noted that the other vibrational transitions from (7.0) to (12.0) should be almost as intense as λ3934.3 (9.0). The three molecular identifications would indicate that the molecules were practically all in the lowest rotational vibrational and electronic level.

McKellar suggested that the identification of λ4300.2 with *CH* could be confirmed if the (0.0) transition of the other electronic system $^2\Sigma \leftarrow\!- {}^2\Pi$ were also observed: the corresponding lines of lowest rotational level are λ3886.32, λ3878.7 and λ3890.15, of relative intensities 3, 1, 2 and of combined intensity somewhat less than λ4300.24. The Harvard Announcement Card No. 526 (June 18, 1940) brought the desired observational confirmation. On a high dispersion spectrogram of ζOphiuchi taken on a fine-grained plate, Adams observed the three new lines of *CH* with the expected intensities. McKellar has now determined the best laboratory wave-lengths of the *CH*-lines and the agreement with Adams' interstellar wave-lengths is gratifyingly close (25). McKellar's suggestions, together with Adams' observations, have provided conclusive evidence of the existence of interstellar molecules.

Other sharp lines observed by Adams are: λ3579.04 (unidentified), λ3745.33 (fairly prominent, unidentified) and λ3874.02. This last line is probably the R(1) transition of *CN*; it is less conspicuous than the R(0) line at λ3874.62. The difference between the rotational levels is 0.00042 volt; the observation of Adams would thus mean that a certain proportion of *CN*-molecules are on the rotational level 1 at 0.00042 volt. This behaviour may be understood by the foregoing considerations, and the evidence in favour of the existence of interstellar *CN*-molecules is, on the whole, quite satisfactory.

Now, if *CH* and *CN* are considered as being definitely present in interstellar space, there is a great probability that other hydrides, such as *NH* and *OH* and possibly also the carbon molecule C_2, may also be found. The lines of *NH* and *OH*, which may be expected, lie in the observable ultraviolet region; the heats of dissociation of these two molecules are of the same order as that of *CH* and we may expect an abundance of *NH* and *OH* similar to or even greater than that of *CH*. The strongest interstellar line of *NH* should be λ3357.8 and that of *OH*, λ3078.4.

We may wonder whether there is still some hope that interstellar gaseous molecules may also be responsible for broader lines, such as those observed by Merrill or perhaps even for a wide band such as that investigated by Beals and Blanchet. Molecules may give rise to broader lines or even to bands in the following cases:

(*a*) if certain equivalent temperatures T_λ are higher than the values of Table I (for example, if the infra-red radiation of the stars and of the interstellar particles in certain spectral regions is larger than was assumed in Table I; or if a region of space is richer in stars or dust; or in regions nearer to the stars, etc.);

(*b*) if, due to peculiar processes (for example, dissociation of more complex molecules, especially of solid particles), the molecules keep a certain rotational energy and if the transitions to lower rotational levels are unusually strongly forbidden;

(*c*) if the probability of the forbidden transitions between two rotational levels is so extremely small that the "populating processes" exceed the "emission processes."

The molecular hypothesis should not be altogether abandoned for the broad lines, although the prospects are not too hopeful (26).

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The molecular hypothesis should not be altogether abandoned for the broad lines, although the prospects are not too hopeful (26).

Another possibility suggested by Merrill (27) and also considered by Beals (20) and others is that these bands would be due to solid particles at the very low interstellar temperature: there is a strong correlation between the intensities of the broad lines and the colour excesses attributed to small diffracting, interstellar particles.

The widths of the absorption bands of a solid are essentially due to the termal agitation and to the broadening of the levels of each constituent (atom or molecule) owing to the interactions of neighbouring particles. In order to explain relatively narrow bands, the required assumptions for solids are a low temperature and weak interactions between the constituents. The first requirement is fulfilled in interstellar space. The second enables us to exclude the metals in the crystalline state (conductors) and the crystals with ionic lattice. In both cases, the interactions are strong and give rise to broad bands, even at very low temperatures. On the other hand, weak interactions are present in molecular crystals and in amorphous metals; hence, these are two possibilities which may lead to satisfactory identifications (28).

If we adopt for interstellar space relative abundances similar to those of stellar atmospheres, we may expect crystals of light elements (solid hydrogen, solid oxygen, ice, CO_2, etc., or mixtures of them). The spectra of such solids at very low temperatures should exhibit great similarities to those of the corresponding atoms or molecules as vapours at high pressure or as liquids, although the influence of the crystalline lattice should be manifest also. But experimental work is completely lacking in this field of optics and is much needed. It should start with the investigation of the absorption spectrum of solid hydrogen at a temperature of about 3°K. Incidentally, the absorption spectrum of solid oxygen has been investigated by Victor Henri (29); the strongest absorption band is at λ5795.7 and it will be recalled that Merrill observed a band at λ5796.9. Although this may be a chance coincidence, it is worthwhile to point it out.

The amorphous metals have also a conspicuous interest. Such solids are obtained by condensation at low temperatures and are favoured by small dimensions. It seems probable that part of the small interstellar "metallic" particles are in the amorphous state. They are insulators and their electric properties are fairly well

known; unfortunately almost nothing is known regarding their optical properties and laboratory work in this field of optics is also urgently needed. The collaboration of cryoscopy and astrophysics will almost certainly be profitable in the future.

McDonald Observatory,
October 21, 1940.

REFERENCES

(1) *Pub. A.S.P.*, v. 46, p. 206, 1934; see also *Ap. J.*, v. 83, p. 126, 1936; P. W. MERRILL and O. C. WILSON, *Ap. J.*, v. 87, p. 9, 1938.

(2) Two other lines were reported later on at λ6203.0 and λ6262.0.

(3) *M.N.*, v. 95, p. 635, 1935.

(4) *Ibid.*, v. 97, p. 212, 1937.

(5) The Internal Constitution of the Stars, 2nd edition, p. 371: 5 per cent. of stars at 18,000°; 10 per cent. at 12,000°; 20 per cent. at 9,000°; 40 per cent. at 6,000° and 25 per cent. at 3,000°.

(6) The equivalent temperature T_λ is such that the actual energy-density for wave-length λ, in interstellar space, is equal to that of equilibrium radiation at temperature T_λ.

(7) For instance, the CO_2-bands, when observed in the laboratory, average about 100 cm.$^{-1}$ in breadth throughout the spectrum.

(8) Private communication.

(9) *Annales d'Astrophysique*, v. 1, p. 39, 1938.

(10) DUNHAM and ADAMS, *Pub. A.A.S.*, v. 9, p. 5, 1937; DUNHAM, *Pub. A.S.P.*, v. 49, p. 26, 1937; *Nature*, v. 139, p. 246, 1937.

(11) *Pub. A.S.P.*, v. 49, p. 26, 1937.

(12) *Nature*, v. 139, p. 840, 1937.

(13) *Ap. J.*, v. 86, p. 483, 1937.

(14) *Ibid.*, v. 86, p. 486, 1937.

(15) If we assume with STRUVE (*Proc. Nat. Acad. Science*, v. 25, p. 36, 1939) $T = 15{,}000°$ and $\delta = 10^{-16}$, we find $n_{CH} \sim 10^{-7} n_C n_H$. It is interesting to compare this abundance of *CH* with the recent determinations of atomic abundances by DUNHAM (*Proc. Amer. Phil. Soc.*, v. 81, p. 277, 1939). DUNHAM finds per cm.^{3}: 5×10^{-8} atom of *Na* I; 4×10^{-11} atom of *Ca* I; 1.4×10^{-7} atom of Ca^+; 1.3×10^{-9} atom of Ti^+. If we take $n_H = 1$ and $n_C = 10^{-2.5}$, we find that n_{CH} is of the same order as n_{Ca}. The identification of interstellar *CH*-molecules is in agreement with STRUVE's view regarding interstellar hydrogen atoms on the basis of his observations of H_α emission in many extended regions of the Milky Way.

(16) The H_2 molecules are particularly abundant, but are unobservable, their absorption bands being in the far ultraviolet.

(17) It is evident that this coincidence was found as a result of a systematic discussion of all possible molecules; no other coincidence having been found, the discussion was not published, except for *CH*. See also P. SWINGS and M. DÉSIRANT, *Ciel et Terre*, v. 5, p. 160, 1939.

(18) *Loc. cit.*, p. 485.

(19) *Annales d'Astrophysique*, v. 1, p. 39, 1938.

(20) *M.N.*, v. 98, p. 398, 1938.

(21) *Ap. J.*, v. 90, p. 630, 1939.

(22) Annual Report of the Director of the Mount Wilson Observatory for the year 1938-1939; issued December 15, 1939.

(23) *Pub. A.S.P.*, v. 52, p. 187, 1940.

(24) The theoretical interstellar abundance of *NaH* is much lower than the abundance of *CH* (owing to the lower heat of dissociation of *NaH* and also to the probably lower abundance of *Na*, compared to *C*).

(25) *Pub. A.S.P.*, p. 52, v. 312, 1940.

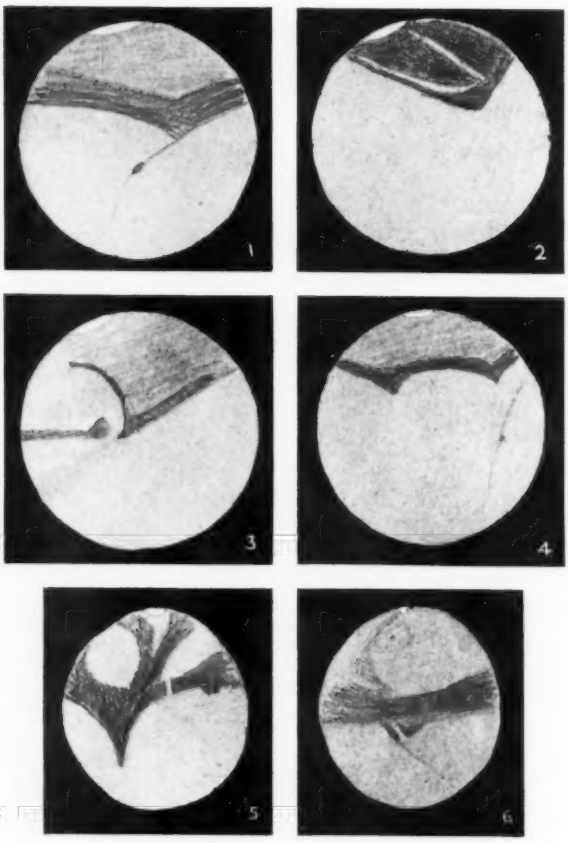
(26) No clear identification is indicated by a systematic examination.

(27) *Phys. Rev.*, v. 52, p. 761, 1937.

(28) P. SWINGS and Y. ÖHMAN, *Observatory*, v. 62, p. 150, 1939; P. SWINGS and M. DÉSIRANT, reference 17.

(29) Probably unpublished. Investigations started in Liége (Belgium) in this general direction were interrupted by the war.

PLATE V



DRAWINGS OF MARS IN 1939

1. July 18, 10.45-10.55 p.m., E.S.T.
   Magnifications used, 100, 150.
   Long. of central meridian, 212°.
2. July 25, 9.55-10.20 p.m.
   Magnification used, 250.
   Long. of central meridian, 140°.
3. August 7, 9.10-9.55 p.m.
   Magnification used, 250.
   Long. of central meridian, 10°.
4. August 26, 7.55-8.25 p.m.
   Magnifications used, 150, 250.
   Long. of central meridian, 185°.
5. September 18, 7.05-7.50 p.m.
   Magnifications used, 150, 250, 300.
   Long. of central meridian, 321°.
6. September 26, 7.15-7.32 p.m.
   Magnifications used, 150, 250.
   Long. of central meridian, 171°.

MARS IN 1939 AS SEEN THROUGH A FOUR-INCH TELESCOPE

By De Lisle Garneau

(With Plate V)

I WAS never so impressed by the planet Mars as I was at this opposition. Although not high above the horizon the ruddy globe offered many interesting features which I had not seen as clearly before. Throughout the summer and early fall I observed Mars twenty-two times and drew its markings. I used my four-inch Lancaster refractor and employed eye-pieces magnifying 100, 150, 250 and 300 times, but most of the observations were made with powers of 150 and 250 and only on three occasions, twice when the sky was exceptionally clear and once on July 26 when the planet was nearest the earth, did I use the ultimate 300-power. I did not examine a map of Mars beforehand, knowing that I would be subject to preconceived ideas, just as a person who from a distance is able to make out on a sign-post the name of a street with which he is already familiar. Thus I was well prepared to put in some useful work, and set out accordingly to look at our "next door" neighbour.

I viewed Mars for the first time on July 12 at 11.10 p.m. (E.D.S.T.). The sky was clear. The first marking that attracted my attention was the South Polar Cap which was quite extensive. Other configurations visible were Syrtis Major and part of Mare Cimmerium.

July 18: Mare Cimmerium visible in its entirety, and extending from its northern tip was the canal Cerberus running northeastward into Trivium Charontis thence continuing north into the canal Hades. (No. 1 in Plate V.)

July 21: Same aspect as on July 18 except for a displacement of its central meridian from 212° to 173°, revealing Mare Sirenum.

July 24: I saw Mare Australis, but not much detail on the surface save for the isthmus of Atlantis.

July 25: Similar to the drawing of July 24 except for two white streaks stretching from the South Polar Cap towards the north. One of these seems to correspond to Atlantis. (No. 2 in Plate.)

July 26: Same general aspect as on previous day. The two white lines are invisible, perhaps on account of a hazy sky above me; yet, on the other hand, Thyle I appears under the Polar Cap.

July 27: Nearest approach. Cloudy sky renders practical observations impossible.

August 5: The following new markings were revealed: On the central meridian, Margaritifer Sinus, but not very conspicuous; to its left Sabaeus Sinus in the shape of a round dark spot; to its right what seems to be Aurorae Sinus.

August 7: A pronounced change has taken place in Sabaeus Sinus. The dark spot has separated from Margaritifer Sinus and a black arc-shaped strip surmounts Sabaeus Sinus in eyebrow fashion as may be seen on drawing number 3 in Plate V.

August 10: This day brings back to view Syrtis Major. A white patch coincides in position with Deucalionis R. The Polar Cap is surrounded by a dark ring.

August 13: A straight dark, thick band joins the South Polar Cap to Syrtis Major. Another one takes off from here and runs into Sabaeus Sinus. The black ring around the Polar Cap still persists.

August 21: Mare Cimmerium has expanded eastward. The canal Boreus with its oasis are visible in the north arctic belt. Ring still around South Polar Cap. No sign of Trivium Charontis with Cerberus and Hades.

August 22: Same view as on July 18 (number 1 on Plate). South Polar Cap receding in size.

August 23: Cerberus has broken away from Mare Cimmerium; this might be due to clouds over the region. Mare Sirenum reappears near the limb.

August 26: Same as July 21. (See number 4 on Plate.)

August 30: Two faint spots north and east of Mare Australis are the only noticeable new markings.

September 11: The globe of Mars has become slightly gibbous. Margaritifer Sinus near the centre of the disk and divided into two parts; Sabaeus Sinus to left has resumed its normal shape and tapers to one point.

September 18: Greatest transformation of Syrtis Major. Besides deepening in tone it has extended farther to the north and its pointed tip has reached far into the north temperate zone. A white gap divides Syrtis Major from Sabaeus Sinus. (Number 5 on Plate.)

September 19: The white gap of September 18 has filled in. Chersonesus and Hellas together blend into a wide white circle above Syrtis Major.

September 21: Faint white patches over Syrtis Major disclose Hellas and Ausonia.

September 24: The markings are more conspicuous and form a band around the equator. Syrtis Parva or Minor becoming visible. Mare Cimmerium protruding into the canal Triton. Elysium appears whitish on the eastern limb. Hesperia in between Mare Tyrrhenum and Mare Cimmerium and quite in evidence. Mare Chronium apparently outstretched between south polar circle and the equator.

September 26: Thyle I may be seen below the polar cap. What seems to be the canal Tartarus is seen emerging from northern tip of Mare Sirenum. South Polar Cap almost invisible. (Number 6 on Plate.)

Summarizing these observations, the outstanding features were as follows:

(1) Syrtis Major, Sabaeus Sinus, Mare Cimmerium, Mare Sirenum, Trivium Charontis and its canals Cerberus and Hades.

(2) The most important changes occurred in first Sabaeus Sinus, second in Syrtis Major.

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Montreal, P.Q.

METEOR NEWS

Observations relating to meteors and meteorites are cordially invited.

A New Book on Meteors Published in the U.S.S.R.

A book entitled "Meteors", by I. S. Astapowitsch and V. V. Fedinsky, has been published by the Academy of Sciences of the U.S.S.R. in Moscow. This volume is dated 1940 and is one in a series published with the purpose of popularizing various branches of science. The book is entirely in Russian, octavo, 126 pp., with 73 illustrations, 6 of these being plates. It is bound in stiff paper covers and cloth backed.

Although I must confess I do not read Russian fluently the general nature of the contents may be gathered from examination of the chapter headings, tabular material, and illustrations. It seems to be a very readable and up-to-date summary of our knowledge concerning meteors and meteorites. Among the subjects covered are:—height determination of meteors, radiants, meteor photography, velocity determination, the structure of the atmosphere, meteor spectra, persistent trains, the form and structure of meteorites, meteor craters, evidence of meteoric matter in space, and practical instructions for meteor observers. The two authors are both authorities in their subject, having carried on active research in this field for many years. The appearance of this book indicates the general interest in meteor research which exists among the Soviet astronomers. It would certainly be a big help in stimulating interest in meteor observing on this continent if a similar volume appeared in English.

P.M.M.

REVIEW OF PUBLICATIONS

Spectra of Long-Period Variable Stars, by Paul W. Merrill. Pp. 107, 9½ x 6½ ins. Chicago, University of Chicago Press, 1940. Price $2.50.

This is the fourth of the series of Astrophysical Monographs sponsored by the Astrophysical Journal. The author has for twenty-five years devoted much time to studies of long-period variables, and as an astronomer at Mount Wilson has had the use of unexcelled equipment. He is the author of a more general book entitled "The Nature of Variable Stars." He thus brings to this very involved field a familiarity and thoroughness that should make this book serve as a standard reference for many years. The treatment is primarily descriptive, and the text is accompanied by plates, graphs, tables and many references.

Following brief introductory and historical sections, a major chapter is devoted to a description of the spectra of the long-period variables at maximum—that phase at which the observations can be most satisfactorily made. This is followed by a description of the changes in spectra with phase. Another chapter deals with several of the famous individual variables, such as Mira, R Aquarii with its nebulosity, and χ Cygni.

In the fifth chapter, dealing with special problems, the author outlines some of the mechanisms that may be used to explain the more conspicuous idiosyncrasies of long-period variable spectra—such as displacements of bright lines, the complicated structure and anomalous intensities of the Balmer emission lines, and the suppression or strengthening of certain lines within a multiplet.

The seventh chapter deals with the general nature and causes of variation, and the comparison of the possibilities of this being a result of instability in single stars with it being an evidence of the existence of companion stars.

The presswork on the book is excellent; the price seems rather high for a book of this size with only paper binding.

F. S. H.

NOTES AND QUERIES

Communications are invited, especially from amateurs. The Editor will try to secure answers to queries.

Staff of the Dominion Astrophysical Observatory

Following the death of W. E. Harper in June last the staff of the Dominion Astrophysical Observatory at Victoria, B.C., has been re-organized and is now:

Head Astronomer	J. A. Pearce
First Assistant	C. S. Beals
Astronomer, Grade 4	R. M. Petrie
Astronomer, Grade 3	A. McKellar
Astronomer, Grade 1	K. O. Wright
Astronomical Assistant, Grade 1	W. H. Stilwell

The Journal wishes to congratulate these men on their deserved promotions.

C. A. C.

The War and the D.D.O. Staff

The war has deprived the observatory of the services of the following members of the staff:

In July 1940, Mr. G. H. Tidy joined the Canadian Navy. He is now Sub. Lieut. Tidy, R.C.N.V.R., and is stationed in Southern England as a radio technician.

In November 1940, Dr. J. F. Heard entered the Air Force. Pilot Officer J. F. Heard, R.C.A.F., has completed a course at the Air Navigation School, Rivers, Manitoba, and is now serving as an instructor in the Air Observers' School, at London, Ontario.

In the same month Mr. W. F. M. Buscombe, engaged as a part-time assistant, entered the Dominion Meteorological Service in a civilian capacity and will be serving as a weather forecaster and instructor in meteorology in connection with the Empire scheme in the R.C.A.F. For the time being he has been able to continue part-time services to the observatory.

In January 1941, Dr. P. M. Millman entered the Air Force and is now Pilot Officer P. M. Millman, R.C.A.F. He is taking an instructors' course at the Air Navigation School, Rivers, Manitoba.

R. K. Y.

MEETINGS OF THE SOCIETY

AT TORONTO

October 8, 1940.—The regular meeting of the Royal Astronomical Society of Canada, Toronto Centre, was held in the McLennan Laboratory, University of Toronto, with Mr. S. C. Brown in the chair.

Dr. P. M. Millman told the members of the new Chant Medal to be offered as encouragement to amateur astronomers in Canada. Nomination forms were available.

The vice-chairman, Dr. D. W. Best, then took the chair and called upon Mr. Brown, who spoke on "Mirror Making for the Amateur". Mr. Brown said that to most people an astronomical telescope is a refractor, and that there were certain advantages to this type of telescope. As far as resolving power, definition and light-gathering power are concerned there is little to choose between the two types. However, the cost of making a reflector is less than for a refractor, so that the reflector appeals to amateur telescope makers. Pyrex was suggested as perhaps the best material for the mirror, though commercial plate glass is fairly satisfactory. Fused quartz is of couse best so far as having a low temperature coefficient is concerned, but is hard to work and requires much patience. Mr. Brown suggested a barrel filled with either water or rocks for a stand, so that the mirror, affixed to this, could be worked from all angles with the tool. The tool is a glass disc duplicating the mirror glass.

It is necessary to decide first of all upon the focal length desired. A ratio of f/8 is most common, so that for a 6-inch objective the focal length would be 48 inches. The coarsest abrasive is used until the centre of curvature is something like 10 inches short of the final length. Mr. Brown particularly warned the members to wash away every trace of one abrasive before starting with the next. He suggested six different grades of abrasives. The spherical shape of the mirror should be attained with the finest abrasive. The next step is to polish the mirror and at the same time to change the shape from spherical to parabolic. Mr. Brown gave complete instructions as to how to make the pitch tool for this part of the work. The final testing by the Foucault method was described. The need for a firm bench and extreme cleanliness throughout the whole work was stressed.

Dr. Millman then spoke on "Recent News about Meteors". Reports of the summer work were not all in, but even so 36 direct photographs and 3 spectra of meteors had been obtained.

The mounting for six cameras designed and in use at the Dunlap Observatory was shown. The photographs taken with this equipment give the speed and direction of the meteor, but other observations at other stations are needed to get the actual position of the meteor in the atmosphere.

Of particular interest was a slide showing the first published meteor spectra.

A. S. Herschel made these observations with a hand spectroscope in 1866. Many of the spectra were shown to be monochromatic. Yellow predominated in many and this Herschel identified with sodium. Dr. Millman's spectra of 1939 and 1940 show much detail in the red, and definitely show the yellow lines of sodium. This is of importance since from 1906 onwards C. C. Trowbridge (d. 1918) tried to show that the yellow recorded by early observers was due to active nitrogen.

October 22, 1940.—The regular meeting of the Toronto Centre was held at the usual place and hour. Mr. S. C. Brown was in the chair.

Mr. Ronald Mathieu, 158 Woodmount Avenue, Toronto, was elected to membership in the Toronto Centre.

Dr. Millman announced the purchase of two new books for the library: *Our Wonderful Universe*, Revised Edition, by C. A. Chant, and *Life on Other Worlds*, by Spencer Jones.

Mr. J. R. Gibbs, F.R.M.S., was then called upon to speak on "Thunder and Lightning". Mr. Gibbs remarked that thunder is always referred to first, perhaps because of its startling nature. Until relatively recently thunder and lightning were mysteries. The similarity between lightning and the sparks from the then new device called the "electrical machine" led Franklin and others to investigate lightning more closely. The electrical nature of lightning was thus established.

Mr. Gibbs briefly discussed and showed slides of the various cloud formations, dealing with the cumulo-nimbus in more detail. According to Mr. Gibbs three kinds of lightning are recognized: diffuse, which is the reflection of a distant storm; linear, which is ribbon-like and forked and more destructive; and third, the fireball, which is a type that is doubted by many, though various observations of it have been reported. Many interesting experiences with lightning were described.

The facts that distant diffuse lightning often has no thunder associated with it, and the lag in the arrival of the thunder after the visual observation of the linear lightning were ably demonstrated with the assistance of Dr. Millman and Mr. Brown. The method of estimating the distance of a storm and whether it is approaching or receding by counting the seconds between the flash and the sound of the thunder was described. The speaker also described the method of photographing lightning with a rotating camera. This disclosed that many of the lightning flashes are multiple, and consist of several discharges occurring in quick succession along a common path. Mr. Gibbs concluded by discussing the possible damage to aircraft passing through a storm. This is of particular importance at the present time.

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